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The Semiconductor Sector by Value Chain Segment: Analysis of Competitiveness and Policy Directions[1)]

SUMMARY

Semiconductors are a key component of electronic devices used in high-tech operations such as computation, control, transmission, conversion, and storage. The chip sector spans manufacturing to downstream industries such as manufacturing equipment and materials.

This paper analyzes the competitive advantages of segments of the semiconductor industry value chain by using qualitative and quantitative metrics. The world's chip superpower is the US, with the largest share of the global semiconductor market and the best competitiveness in R&D and design on the planet. Taiwan and Korea, meanwhile, are more competitive in semiconductor manufacturing. Based on an analysis of overall competitiveness, Korea is fifth among the six biggest players in the sector, which include the US, Japan, and Taiwan, but is at a competitive disadvantage compared to its peers outside of the memory semiconductor sector, where it is dominant. Moreover, China has surpassed Korea in overall competitiveness since the 2020 rankings.

It is important for Korea to maintain its competitiveness in memory semiconductors, a sector where it has superior competitiveness, through the development of next-generation chips and a "super gap" strategy to maintain its lead. In the fabless segment for system semiconductors, which Korea is relatively weak in, alignment with demand industries is needed to drive growth and the foundry segment must secure market share in high-tech segments.

1) This paper is an excerpt from *A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry*, by MOTIE and KIET (2021).

1. Introduction

Semiconductors are an essential component of electronic devices used not just in everyday life but also in future-oriented strategic sectors such as advanced weapons and aerospace. Against this backdrop, the US and China are locked in a power struggle over semiconductors, and a chronic supply shortage of automotive chips has prompted major economies to develop their own semiconductor industries. The US enacted the CHIPS and Science Act to revive its semiconductor manufacturing sector, while the European Union is working to boost domestic chip output. Both the private and public sectors in Taiwan and Japan are expanding support to advance their semiconductor industries.

Korea's semiconductor industry took off in the mid-1980s. Growth has been concentrated in the memory semiconductors subsegment of the industry. Today, chips account for approximately 20% of the nation's exports. Korean semiconductors make up nearly 60% of the global memory semiconductor market, second only to the US, so Korean semiconductors have a major presence not just domestically but also globally.

Korea retains a significant position in the global semiconductor chain as a memory chip supplier, but as major economies promote their own products, growing competitive pressure on the global market will threaten Korea's standing. Accordingly, this paper analyzes the strengths and weaknesses of the semiconductor sector in Korea and major economies from a value chain perspective, diagnoses competitive advantage, and presents a path forward for the Korean semiconductor industry. This approach is expected to keep the Korean sector competitive amid a struggle for hegemony in the global chip market and also compensate for its weaknesses in a bid to continue the sector's growth trajectory.

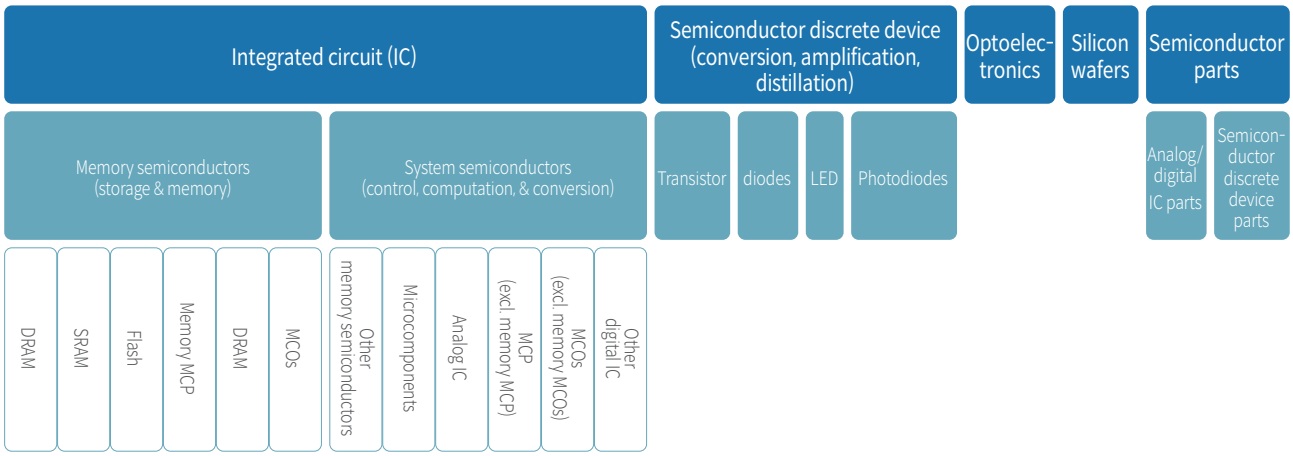
2. Latest Developments in the Semiconductor Industry

(1) Definition and Scope

Semiconductors are a core component of electronic devices used in high-tech operations such as computation, control, transmission, conversion, and storage. The semiconductor sector spans manufacturing to downstream industries such as manufacturing equipment and materials. Chips are also a key component a diverse array of devices from home appliances to advanced robots, and their scope includes electronic integrated circuits, discrete devices, optoelectronics, and silicon wafers.

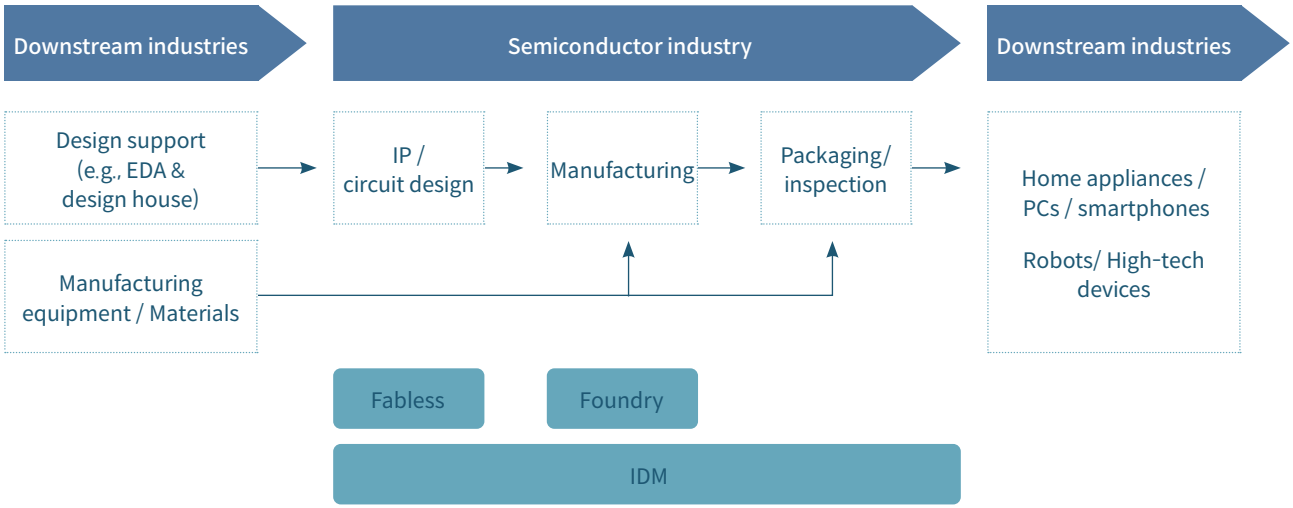
While the industry is built around chip manufacturing, its ecosystem encompasses equipment and materials. The scope includes integrated device manufacturers (IDMs), active in diverse manufacturing processes, fabless companies dedicated to semiconductor design, chipmaking foundries, back-end processing companies to inspect and package wafers, equipment companies, and materials suppliers.

<Figure 1> Semiconductor Types



Source: KIET (2019), as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry, by MOTIE and KIET (2021)

<Figure 2> Semiconductor industry ecosytstem



Source: KIET (2020) as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

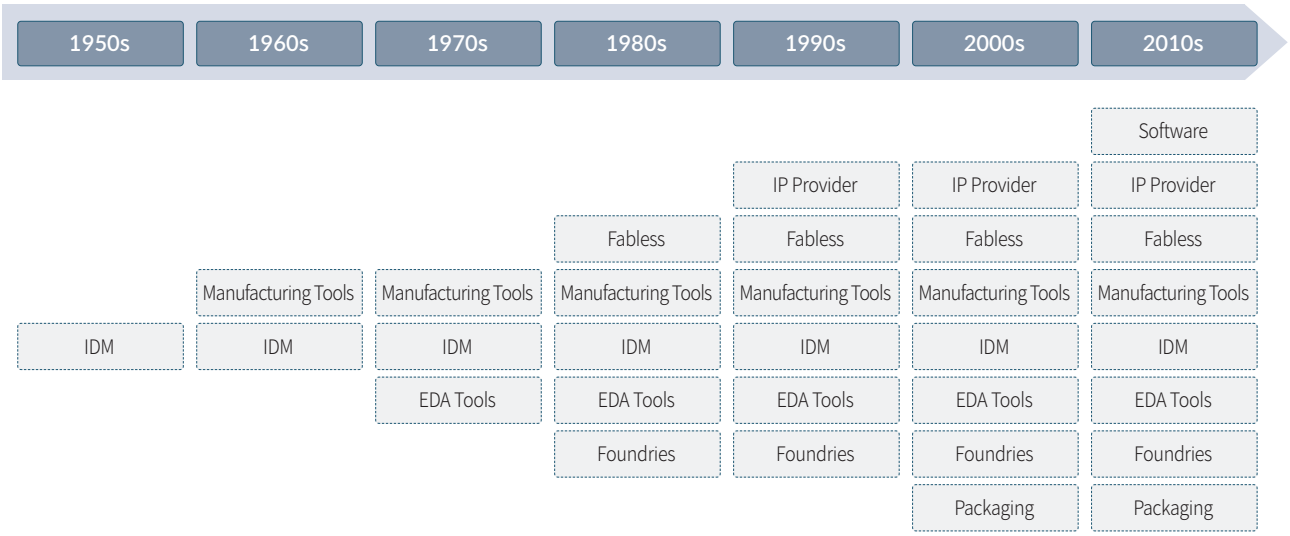
(2) Characteristics of the Semiconductor Industry and Changes in Global Trends

Semiconductors are largely divided into two categories: memory semiconductors, which store and retain data, and system semiconductors, which process data. Memory chips account for under 30% of overall semiconductor sales; system semiconductors make up over 70%. For IT devices, a range of types are used according to the purpose of a product, but most devices use both memory and sys-

tem semiconductors. As memory semiconductors are mass-produced in a standardized format, prices fluctuate according to demand and supply. In contrast, system semiconductors are mostly produced for custom orders to perform specific functions, so supply and demand dynamics remain steady, with marginal price volatility. Among these types of chips, those for CPUs, APs, and communications are general purpose chips, and supplied via mass production, rather than being custom made. As suppliers have the upper hand in the market, these semiconductors can still deliver high added value.

Memory chips, however, have a wider scope of applications, as they are not designed to perform specific functions or limited to a select scope of IT products. But they are sensitive to economic cycles because of their low prices, and the demand side has the advantage in the market. The semiconductor industry has evolved beyond integrated device manufacturers (IDMs). With the diversification of semiconductor types and the expansion of the market, chipmakers began to specialize in processes such as design, manufacturing, packaging, and testing, making the value chain more complicated. Looking at the timeline, (Figure 3) we can see that when semiconductors were first developed in the 1950s, there were only a few IDMs that handled of all stages of the production process. With the emergence of companies specializing in each chipmaking process, the industry in the 1980s vertically separated into design-only (fabless) and manufacturing-only (foundry) companies. In the beginning, IDM was the predominant type of semiconductor business, as the industry was small in scale and initial investment in manufacturing facilities was limited. Such investment has since grown, spurring the growth of fabless companies specializing in design. And the market for pure foundry players such as Taiwan's TSMC has rapidly expanded thanks to a higher number of fabless companies and growing demand. Taiwanese companies have a dominant position, with over 60% of the global foundry market, which was big news in Korea vis-à-vis system semiconductors.

<Figure 3> Evolution of Semiconductor Company Types



Source: "Beyond Borders — The Global Semiconductor Value Chain" (2016) as quoted in *A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry* by MOTIE and KIET (2021)

(3) Current Status of Supply and Demand and Outlook

Semiconductor manufacturing is divided into IDM, fabless, and foundry companies. As Korea's chip output has grown thanks to memory semiconductors, IDM companies are the most developed. In its early days, the domestic semiconductor industry was an outsourcing service provider for the back-end process of packaging. The government aggressively began fostering memory semiconductors from 1983, when Samsung Electronics started to independently manufacture DRAM. As a result, memory chips over the past five years have accounted for over half of Korea's semiconductor exports (Table 1); this figure is down from 70% during the chip boom from 2017 to 2018.

<Table 1> Memory Semiconductors as a Percentage of Korea's Chip Exports

(Units: USD 100 mln, %)

	2016	2017	2018	2019	2020	2021
Total semiconductor exports	622	979	1,267	939	992	1,280
Memory semiconductor exports	352	672	941	630	639	824
Export mix of memory semiconductors	56.6	68.6	74.3	67.1	64.4	64.4

Source: KITA (2021) as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021) and updates in 2021

As the first country to develop semiconductors, the US has had a large share of the global market since the beginning. In the 1980s, Japan commanded a significant market share, but was overtaken by Korea in 2013.

As a core component of electronic devices rather than an end product, semiconductors are highly sensitive to the business cycles of downstream industries. The chip market recorded a robust 10-year CAGR of 3.8% from 2010-20. With the development of new sectors related to the Fourth Industrial Revolution such as artificial intelligence, the Internet of Things, and self-driving vehicles, demand for semiconductors is anticipated to grow and further expand the semiconductor market.

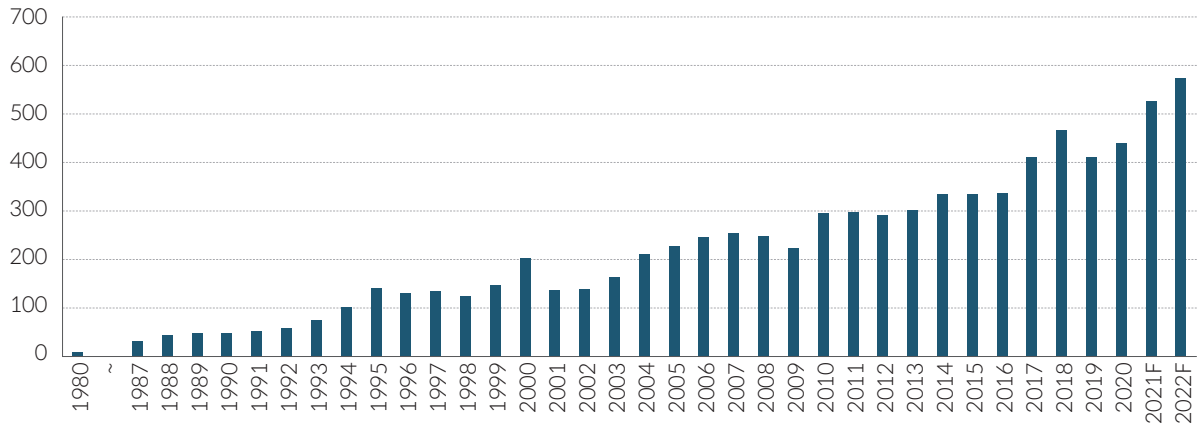
<Table 2> Semiconductor Sales by Country and Global Market Share

(Unit : USD mln)

Market share	2016	2017	2018	2019	2020	2021
Total	354,669	431,994	485,046	428,569	472,659	587,446
Korea	58,589	92,303	114,628	79,002	87,050	116,590
(%)	16.5	21.4	23.6	18.4	18.4	19.8
US	184,303	215,221	235,709	217,057	240,472	292.443
(%)	52.0	49.8	48.6	50.6	50.9	49.8
EUss	33,580	37,969	41,552	40,746	43,680	51,806
(%)	9.5	8.8	8.6	9.5	9.2	8.8
Japan	36,872	41,952	44,796	42,746	43,500	51,945
(%)	10.4	9.7	9.2	10.0	9.2	8.8
Taiwan	23,413	24,396	25,903	25,054	32,522	48,738
(%)	6.6	5.6	5.3	5.8	6.9	8.3
China	13,028	16,558	18,755	20,250	21,680	21,600
(%)	3.7	3.8	3.9	4.7	4.6	3.7

Source: KSIA (2021) and OMDIA (2021) as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021) and updates in 2021

<Figure 4> Growth of the Global Semiconductor Market



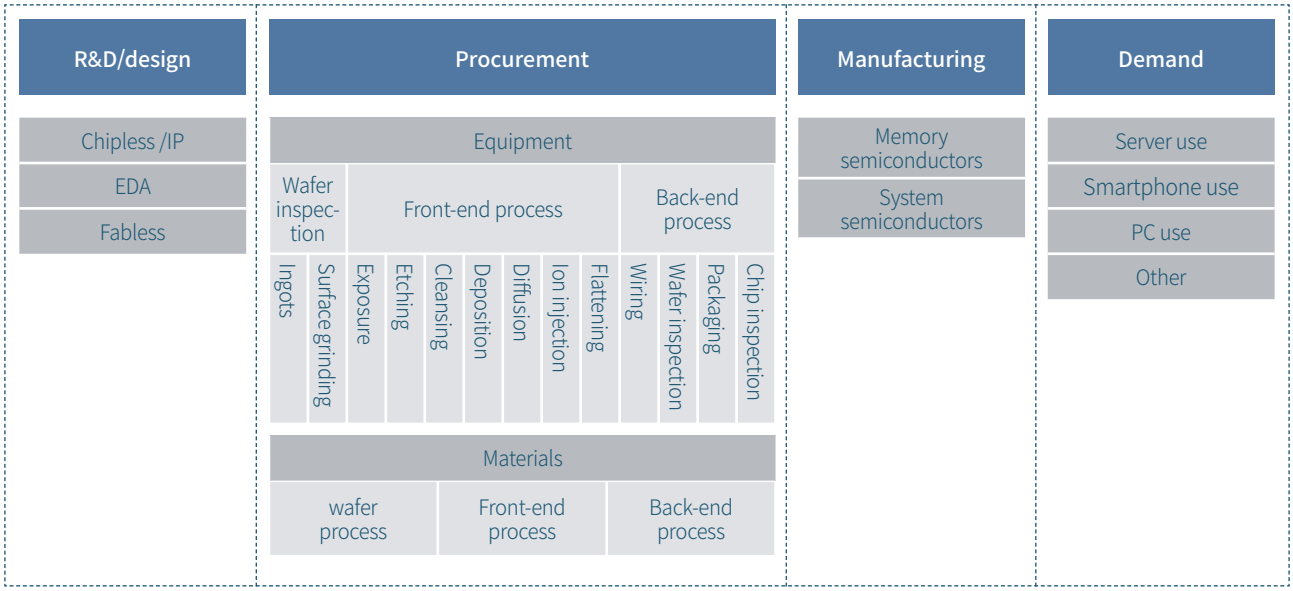
Source: WSTS (2021) and IC Imsights (2021) as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021) and updates in 2021

3. Analysis of the Value Chain Structure of the Semiconductor Industry

(1) Value Chain Structure

The value chain structure for the semiconductor industry comprises the R&D and design, procurement, manufacturing, and demand stages. Semiconductor R&D takes place simultaneously for products and manufacturing processes in the circuit design stage, and R&D in the manufacturing stage accounts for a large share of all R&D. Semiconductor design includes block and circuit designs. The procurement stage of the value chain secures the equipment and materials needed to produce semiconductors in specific stages of the manufacturing process. As semiconductor R&D is also underway in manufacturing processes, the procurement of manufacturing equipment and materials requires close collaboration with relevant vendors. Chip manufacturing can be divided into two parts: front-end processes, where blank wafers made from ingots are fabricated to produce semiconductor characteristics, and back-end processes, where complete wafers are packaged and inspected. During the back-end process of packaging, processed wafers are diced into chips and data input and output devices are externally connected to protect the chips, wiring, and power supply. Post-production wafers and packaged chips are then inspected. From a marketing perspective, memory and system semiconductors exhibit several differences. The market for system semiconductors is driven by the supply side, as the chips are custom-made for specific products. In contrast, the market for memory semiconductors is driven by the demand side, as memory chips are standardized and there is no restriction on supplier selection. Moreover, the small and lightweight nature of semiconductors incurs low logistics costs.

<Figure 5> Value Chain Structure of Semiconductor Industry



Source: KIET (2020) as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

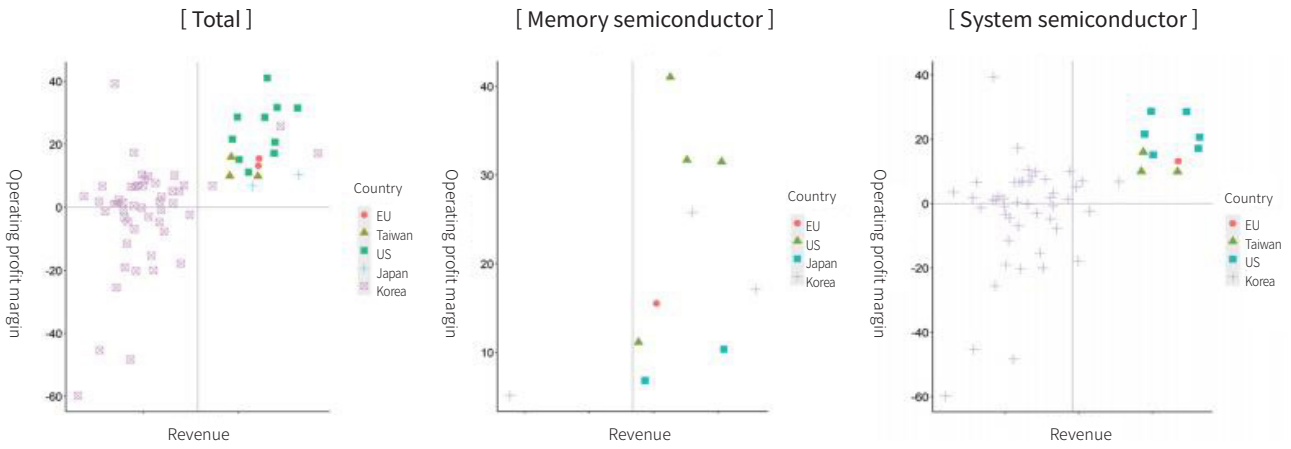
(2) Value Chain Characteristics by Country

The major global players in the semiconductor industry are Korea, the US, Taiwan, China, Japan, and the EU. Notably, Korea has an extensive presence across the value chain, ranging from R&D design to procurement of materials, parts, and equipment to manufacturing. Three-year average revenue varies significantly from company to company; firms in the US and Japan boast higher figures than their Korean counterparts. A high percentage of Korean businesses record positive operating margins; other countries have businesses with operating margins of over 10%. The US and Japan display an even distribution with average revenues, but Korea and Taiwan have more companies whose revenues sit below the global average.

In semiconductor R&D and design, American companies hold a dominant position on the global market, and thus their three-year average revenues and operating margins are very high. Given the characteristics of memory semiconductors, IDM companies also conduct R&D design, and thus market players are large in size but few in number, yielding sound operating profits. In the system semiconductor sector, foreign companies generate robust sales and higher operating profits than those in Korea.

As semiconductor manufacturing equipment requires massive capital investment, manufacturing has fewer players than in the rest of the value chain. Korea and the US are market leaders in memory semiconductors and yield modest operating profits. There are more system semiconductor manufacturers than memory chipmakers, and Taiwanese manufacturers lead the global market. Due to heavy capex requirements, chipmakers are limited in number despite high margins. That said, as countries have announced policy actions to support domestic chipmaking, close monitoring of market developments is a must. Semiconductor materials are largely the same for both memory and system semiconductors, and Japanese and US companies are leaders in both in the global market. A critical semiconductor material is the silicon wafer, which is processed to manufacture memory and system semiconductors. With chip development in the early stage, the US saw the corresponding development of the materials and equipment sector, whereas Japan saw the materials segment advance faster than semiconductor manufacturing segment. Recently, Korean makers of semiconductor materials have shown growth, but are small in scale with relatively low revenue and thin operating margins compared to their overseas counterparts. Overall, semiconductor materials companies enjoy healthy operating margins.

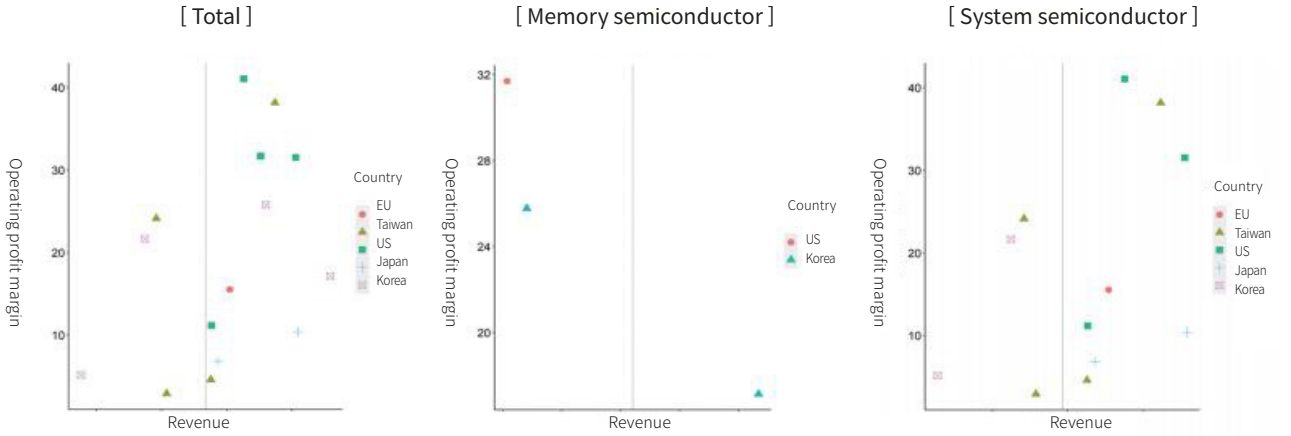
<Figure 6> Semiconductor R&D and Design Companies: Revenue and Operating Profit



Source: A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

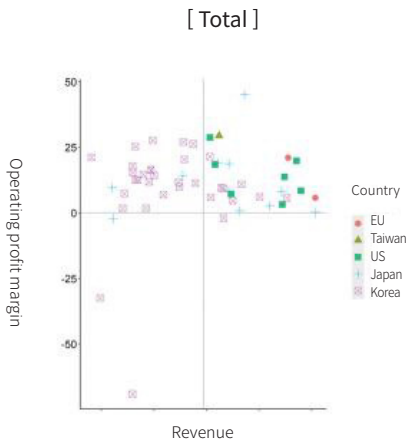
As with semiconductor materials, chip manufacturing equipment does not differ by chip type. US and Japanese companies have leading positions in the semiconductor manufacturing equipment segment as well. Lately, ASML of the Netherlands has become the exclusive supplier of high-priced EUV (extreme ultraviolet) equipment. With the development of semiconductor manufacturing technologies, related equipment also requires cutting-edge know-how and has grown more expensive. As a result, Korean companies are at a competitive disadvantage compared to their counterparts in the US and Japan in terms of financial capacity and technology. But Korea has several of the world's leading semiconductor manufacturers, including Samsung Electronics and SK Hynix, and small domestic equipment manufacturers have upscaled through collaborations with them.

<Figure 7> Semiconductor Manufacturers: Revenue and Operating Profit



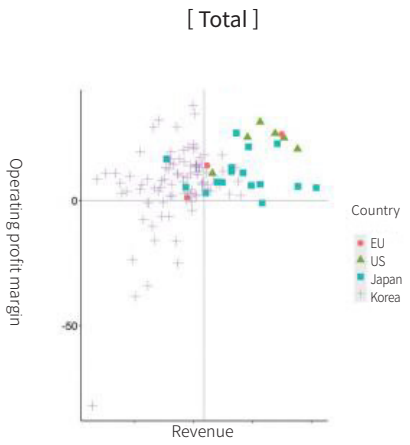
Source: A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

<Figure 8> Semiconductor Materials Suppliers: Revenue and Operating Profit



Source: A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

<Figure 9> Makers of Chipmaking Equipment: Revenue and Operating Profit



Source: A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

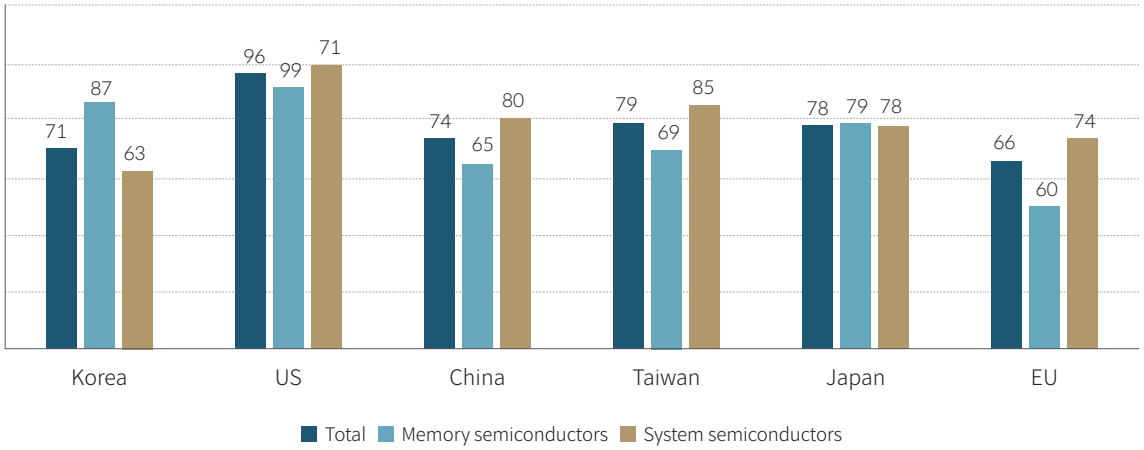
4. Competitive Advantage of the Semiconductor Industry: Diagnostic Results

This paper evaluates competitive advantage factors of the semiconductor industry by value chain segment using qualitative and quantitative metrics to measure competitiveness. By category, this paper divides semiconductors into memory chips and system chips, and compares Korea's competitiveness relative to the competitiveness of the US, Japan, EU, Taiwan, and China. This paper classifies the value chain segments of the chip industry into R&D and design, procurement, manufacturing, and demand. The qualitative analysis was based on the results of the Delphi survey of semiconductor experts

in industry, academia, and research centers. The qualitative analysis used a grading scale based on 256 semiconductor manufacturers, materials suppliers, and equipment makers (redundancy allowed) grouped in their respective stages of the value chain in six countries including Korea, the US, and Taiwan, subject to competitive advantage analysis and corporate financial data.2)

The US topped the list in terms of overcall competitiveness in the semiconductor industry, while Korea ranked at the bottom in system semiconductors, trailing Japan and Taiwan. The US (96) was the world's most competitive semiconductor player across the board, followed by Taiwan (79), Japan (78), China (74), Korea (71), and the EU (66), in that order. The US was also the most competitive in both system (99) and memory semiconductors (91), while Taiwan ranked low in memory chps (69) but high in system semiconductors (85). Korea was very competitive in memory semiconductors (87) but ranked at the bottom in system semiconductors (63) and also ranked last in the overall evaluation. Korea's average score was 87 in memory semiconductors, equivalent to 94%-96% of the world leader's levels. By country, the US topped the list with 91 points, followed by Korea (87), Japan (79), Taiwan (69), China (65), and EU (50). Korea's score of 63 in system semiconductors was equivalent to 86%–90% of the world's top levels. By country, the US received the highest score of 99, followed by Taiwan (85), China (80), Japan (78), EU (74), and Korea (63).

<Figure 10> 2021 Competitive Advantage Evaluation: Global Semiconductor Industry



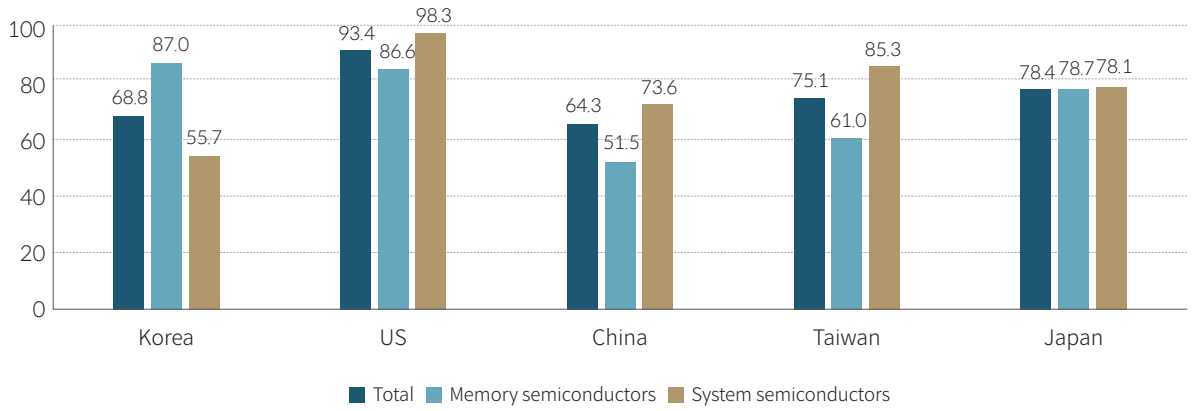
Source: Delphi survey results of industry researchers as quoted in A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

Note: 100 points for world's best; 90 for 97%–99% of world's best; 80 for 94%–96%; 70 for 91%–93%; 60 for 86%–90%; 50 for 81%–85%; 40 for 76%–80%; 30 for 71%–75%; 20 for 66%–70%; and 10 for below 65%

2) The grading scale is 100 points for the world's best; 90 for 97%–99% of the world's best; 80 for 94%–96%; 70 for 91%–93%; 60 for 86%–90%; 50 for 81%–85%; 40 for 76%–80%; 30 for 71%–75%; 20 for 66%–70%; and 10 for below 65%.

<Figure 11> Comparative advantage analysis results: semiconductors (2020)

(World's best = 100 points)



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In 2020, KIET conducted a competitive advantage analysis using the same methodology to compare the competitive advantages of Korea, US, China, Taiwan, and Japan. The US (93.4) was tops in terms of overall competitiveness, followed by Japan (78.4), Taiwan (75.1), Korea (68.6), and China (64.3). According to the 2020 survey, the US remained the most competitive, while Japan and Taiwan and Korea and China switched their rankings from 2021. The change in the rankings between Japan and Taiwan was attributed to a global chip shortage that highlighted the importance of foundries. The difference in the new rankigns between Korea and China was due to the rapid growth of Chinese fabless companies and the higher growth potential of the Chinese semiconductor industry, which can make memory semiconductors beginning with NAND flash production. China needed just a year to overtake Korea in overall semiconductor competitiveness.

5. Policy Direction and Tasks

Korean policy toward promoting the domestic semiconductor industry can be summed up in three directions (Figure 12). First, the government is sharpening the competitiveness of semiconductor R&D and design to beef up R&D and design capabilities in memory semiconductors, a source of competitive advantage for the nation, as well as in system semiconductors, a source of competitive disadvantage. Notably, policy support is growing for businesses in the fabless segment, which has a promising outlook. Secondly, the government seeks to ensure stable procurement by developing core technologies in semiconductor manufacturing equipment and materials, a sector in which Korea trails more advanced market players. Finally, the government seeks to make Korea a global chip power by fostering

the system semiconductor industry. Such efforts aim to make semiconductor demand more resilient to economic cycles by ratcheting up promotional measures for the system semiconductors market, which is driven by the supply side.

The development of the Korean semiconductor industry requires strategies tailored to specific value chain segments as follows. First, preemptive investment and large-scale R&D are needed to defend Korea's competitive advantage in memory semiconductors. This requires technological advancement for next-generation memory semiconductors, the development of world first cutting-edge technologies, and the prevention of technology leaks. Other measures include protecting talent and preventing brain drain. For the fabless segment that designs system semiconductors, expansion of the fabless market is needed by aligning R&D with customer industries and creating clusters. The foundry segment needs growth by promoting exchanges between domestic foundries and fabless companies. Finally, the manufacturing equipment and materials sector needs to use more domestically-developed technologies, and globally competitive companies in this sector need to be developed through win-win collaboration with domestic semiconductor companies.

<Figure 12> Policy Directions for the Development of the Domestic Semiconductor Industry

(1) Enhance competitiveness in semiconductor R&D and design	• Korea, a global leader in memory semiconductors, has competitive advantages in design and manufacturing technologies for memory semiconductors (DRAM and NAND flash), but lags in system semiconductor R&D and design. • Given the strong potential of the fabless segment and high rankings of fabless companies on the list of revenue-generating companies in the global semiconductor market, the Korean government should seek to make domestic fabless companies more competitive.
(2) Ensure stability in procurement by developing core-enabling technologies in semiconductor manufacturing equipment and materials	• As the US was where the semiconductor industry was born, followed by Europe and Japan, Korea is behind in the semiconductor materials and manufacturing equipment segments. Accordingly, the Korean government seeks to ensure stability in procurement through domestically developed technologies
(3) Reinvent Korea as a global semiconductor power in the truest sense by promoting the system semiconductor industry	• While the demand-driven memory semiconductor market is cyclical, suppliers can control the market for system semiconductors. • Given the importance of semiconductor exports as a proportion of Korea's overall shipments overseas, the system semiconductor sector needs enhancement to make Korea a global chip power and make the semiconductor industry resilient to economic cycles.

Source: A Project to Build a System to Diagnose Industry Competitiveness Based on Value Chain Segments: Semiconductor Industry by MOTIE and KIET (2021)

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